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|---|
| AFSC, USAF ltr, 2 Mar 1972 |

Air Force Material.. .. ..ratory
Research and ..chnology Division
Wright-Patterson Air Force Base, Ohio

Materials Applications Division

EVALUATION REPORT

..EDGE OPENING LOADING FRACTURE TOUGHNESS TEST SPECIMEN

Re..... .. AA 65-30                           Date: 2 August 65

Proje.. .r 7..106                             Type Evaluation: Comparative

## I.   JRPOSE

..e purpose of this investigation and analysis was to evaluate the
..edge opening loading (WOL) specimen in fracture toughness testing
..nd to present the results at the ASTM E-24 Fracture Toughness Testing
..ommittee Meeting in the Fall of 1965.

## II.   ..ACTUAL DATA

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d. ..t. .ng ..ccurate plain strain fracture toughness values, a need will always
exist . .. a ..pecimen which will give the greatest economy relative to the amount
of ..... .al ..equired, low testing machine capacity and minimum manpower ..require-
..ents

. D..ring the past two years, considerable work has been done c.. the
devel.. ..nt ..f a small specimen for fracture toughness testing by Wes... ..c ..e
Elect.. Co..oration. The specimen was developed primarily to determine the
effe.. n..clear environment on the fracture toughness of reactor structural
mate. .. ..

..   ..s Wedge Opening Loading fracture toughness test specimen, ..bbre-
..at.. ..L, ..ppears to have potential value in testing th..ck section materials
w..e.. th. ..terial available for specimen fabrication is limited.

. . ..aterials used and the testing program performed are presented in
App.nd. I.

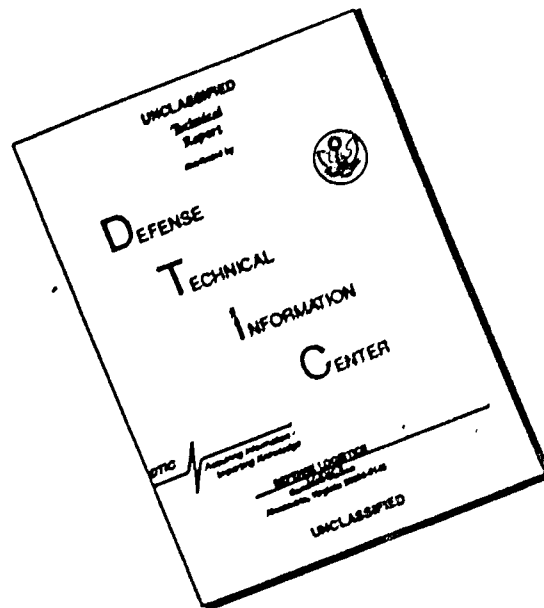. . . test results and discussion are presented in Appendix ..I.

## III.   NC.. ..IONS

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reac.. na.. ..ed and easily reduced.

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Air Force Materials Laboratory
Research and Technology Division
Wright-Patterson Air Force Base, Ohio

Materials Applications Division

EVALUATION REPORT

WEDGE OPENING LOADING FRACTURE TOUGHNESS TEST SPECIMEN

Report Nr:  MAA 65-30                    Date:  2 August 65

Project Nr:  738106                      Type Evaluation:  Comparative

I.  PURPOSE

The purpose of this investigation and analysis was to evaluate the
wedge opening loading (WOL) specimen in fracture toughness testing
and to present the results at the ASTM E-24 Fracture Toughness Testing
Committee Meeting in the Fall of 1965.

II.  FACTUAL DATA

1.  Although a number of specimen types exist which are capable of
determining accurate plain strain fracture toughness values, a need will always
exist for a specimen which will give the greatest economy relative to the amount
of material required, low testing machine capacity and minimum manpower require-
ments.

2.  During the past two years, considerable work has been done on the
development of a small specimen for fracture toughness testing by Westinghouse
Electric Corporation.  The specimen was developed primarily to determine the
effect of nuclear environment on the fracture toughness of reactor structural
materials.

3.  This Wedge Opening Loading fracture toughness test specimen, abbre-
viated WOL, appears to have potential value in testing thick section materials
whenever the material available for specimen fabrication is limited.

4.  The materials used and the testing program performed are presented in
Appendix I.

5.  The test results and discussion are presented in Appendix II.

III.  CONCLUSIONS

1.  The results of these tests indicate that the WOL specimen yields valid
$K_{Ic}$ data, while requiring low applied loads and rendering test records which are
readily analyzed and easily reduced.
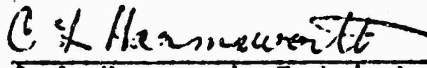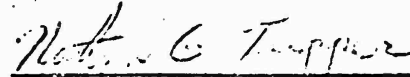
## IV. RECOMMENDATIONS

1. The WOL specimen type should be considered for plain strain fracture toughness testing where the material form is compatible and load capacity and/or material supply are limited.

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### PUBLICATION REVIEW

This report has been reviewed and is approved.

*D. A. Shinn* (signature)

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## Materials

The materials utilized were two aluminum alloys: 7001-T75 and 7079-T6, in the form of scraps from forgings used on a previous test program. The tensile and fracture toughness properties of the materials were determined and reported in AFML-TR-65-150. The existence of these scraps, while limiting the number of specimens, provided an excellent opportunity for evaluating the specimen itself. All materials processing history, chemistry and heat treatment also have been reported in AFML-TR-65-150, but average tensile properties are repeated below for convenience.

| Alloy | Test Direction | Yield Strength .2% Offset (Ksi) | Ult. Tensile Strength (Ksi) | % Elong. |
|-------|----------------|------------------------------|----------------------------|----------|
| 7001-T75 | Longitudinal | 70.4 | 80.5 | 22.0 |
|          | Transverse   | 70.6 | 79.5 | 15.9 |
| 7079-T6  | Longitudinal | 69.3 | 77.4 | 15.2 |
|          | Transverse   | 68.8 | 77.5 | 13.5 |

## Test Procedure

A specimen drawing is presented in Figure 1. Four specimens each (two longitudinal and two transverse) of 7001-T75 and 7079-T6, were fatigue precracked at 25 per cent of yield stress prior to fracture toughness testing in an Instron TTC testing machine at a crosshead rate of .02 in/min. Uncalibrated crack opening displacement was measured with a clip-on gage which was inserted into the specimen notch. Load-displacement curves were plotted, from which pop-in loads were determined. Pop-in events were readily determined from the test records and were invariably audible.

Stresses at the crack tip were determined according to the equation

$$\sigma_N = \frac{P}{Bh} \left( \frac{6 \left(c + \frac{h}{2}\right)}{h} + 1 \right)^*$$

where P = applied load
 B = specimen thickness
 h = uncracked depth
 c = distance from load axis to crack tip
 see Figure 1 for above dimensional designations

The plain strain fracture toughness, $K_{Ic}$, was determined from the equation

$$K_{Ic}^2 = \frac{C_1 \sigma_N^2 c}{(1-\nu^2)}^*$$

---

[*] A. J. Bush and W. K. Wilson, "Determination of Energy Release Rates for Biaxial Brittle Fracture Specimen", AEC Research and Development Report WERL-8844-2, August 1964.

where: $\sigma_N$ = applied stress at the crack tip

   $c$ = distance from load axis to crack tip

   $\nu$ = Poisson's ratio

   $C_1$ = compliance factor

## Results

The data shown in Table 1 are the average of two or more tests for each specimen geometrical configuration tested. The single edge notch (SEN), center notch (CN), slow notch bend (SB), and surface flaw (SF) specimens' data in Table 1 were previously generated prior to this investigation by the Design Information Inhouse Facility of the Materials Information Branch. The data obtained under this evaluation was generated from the same forgings as the above mentioned previously generated data. The data from all specimens are grouped according to crack plane orientations and crack propagation directions in cartesian coordinates as shown in Figure 2. The results were also averaged and are presented in Figure 2. The crack planes and propagation directions are oriented with respect to the two materials processing direction as shown in Figure 2 and pictorially presented in Figure 3. The average $K_{Ic}$ (of the previously generated data from the specimens of various geometrical configurations) as compared with the WOL specimen is summarized in Table 2.

## Discussion

One may conclude from observation of the data and cracks' description, tabulated in Tables 1 thru 2, plotted graphically in Figure 2 and described in Figure 3, respectively, that crack plane orientation and propagation direction has a definite effect on resulting $K_{Ic}$ data. The crack propagation direction appears to have the greater effect based upon the limited tests performed. The results from an identical crack propagation direction and different crack plane orientations seem to correlate better than results from the same crack plane orientation and various propagation directions. This is with respect to each material of the same heat and processing condition. On this basis, results on 7001-T75 and 7079-T6 using the WOL specimen agree very well with previous results using other specimen types cracked in the X crack propagation direction. As shown in Table 2, the X direction average results for the WOL specimen's $K_{Ic}$ of 7079-T6 and 7001-T75 aluminum alloys are 94.0 and 99.9 per cent, respectively, in agreement with average data generated on various other fracture specimens. The Y direction data of the WOL specimen for the above respective alloys are within 81.5 and 80.5 per cent agreement as can be observed from Table 2 also. With reference to Figure 2, the 7079-T6 alloy agreement is good in the Y direction. This disagreement is not as serious as it appears, since previous tests on this particular forging have shown that the material (7079) is severly inhomogeneous and the number of WOL specimens were limited to such an extent that good average values were not obtained. In this regard, it should be noted that the 7001-T75 material was much more homogeneous.

As indicated above, fracture toughness results are greatly influenced by grain structure and the presence of inhomogeneities. With highly worked microstructures, the relative orientation of the crack plane and propagation direction can greatly influence the fracture toughness data obtained and should therefore be noted. The presence of inhomogeneities can affect results for two reasons. The first is that since the equations for calculating $K_{Ic}$ are based on the

material being nearly an elastic continuum, the presence of inhomogeneous
volumes leaves the equations somewhat suspect. The second, and for a more
important reason, is that cracks propagating through inhomogeneous regions
quite simply have environments different from each other and different from
cracks propagating in regions without inhomogeneities. For this reason, micro-
structure should be examined and noted when reporting results, especially if
there is considerable scatter in the data.

Lastly, it should be observed from the crack planes noted in Table 2
under "Specimen Type" and illustrated in Figure 3 that in binary space the crack
planes are in the XZ and YZ reference planes for the comparative specimens'
fracture data generated prior to this evaluation. On the other hand, the crack
plane orientation for the WOL specimen tested in this program is in the XY
reference plane. However, for the same material and crack propagation direction
the fracture toughness results are in agreement for the average of the SEN, SB
and CN specimens versus the WOL specimen results. Therefore, the crack plane
orientations of the specimen data generated prior to this program and used as
a comparison with the WOL crack plane data generated in this evaluation as
summarized in Table 2 and sketched in Figure 3 does not appear to constitute
a fallacy in the comparison. However, in a future program of this nature,
crack planes oriented the same in binary space should also be investigated.

Since crack plane orientation did not appear to be significant, the
WOL specimens fabricated for this program were not oriented the same as Figures
3A thru D with respect to the working direction. It should be noted also from
Figure 3 that the crack plane is parallel to the specimen thickness, and the
crack propagation direction is perpendicular to the thickness. Material line of
reference is the working or forged direction which is the Y direction in Figure 3.

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## TABLE 1

### AVERAGE $K_{Ic}$ VALUES (KSI $\sqrt{in}$ )(1)

| Crack Description | Material | SEN | SF | SB | CN | WOL |
|---|---|---|---|---|---|---|
| XZ-Z | 7001 | -- | 29.0 | 24.6 | -- | -- |
| XZ-X | 7079 | 27.5 | -- | -- | 25.9 | -- |
|  | 7001 | 20.9 | -- | 28.7 | 16.1 | -- |
| YZ-Y | 7079 | 30.8 | -- | -- | 26.2 | -- |
|  | 7001 | -- | -- | -- | 20.4 | -- |
| YZ-Z | 7079 | -- | -- | 30.4 | -- | -- |
|  | 7001 | -- | 25.7 | -- | -- | -- |
| XY-Y | 7079 | -- | -- | -- | -- | 23.2 |
|  | 7001 | -- | -- | -- | -- | 16.4 |
| XY-X | 7079 | -- | -- | -- | -- | 25.2 |
|  | 7001 | -- | -- | -- | -- | 22.1 |

Legend:  SEN - Single Edge Notch Specimen
SF  - Surface Flaw Specimen
SB  - Slow Bend Specimen
CN  - Center Notch Specimen
WOL - Wedge Opening Loading Specimen

(1) Average $K_{Ic}$ values for each specimen configuration with respect to crack plane orientation and crack propagation direction.

## TABLE 2

### AVERAGE $K_{Ic}$ VALUES (KSI $\sqrt{in}$ )(2)

| Propagation Direction | 7079-T6 | 7001-T75 | Specimen Type |
|---|---|---|---|
| X | 26.7 | 21.9 | Average of SEN, SB and CN (XZ-X) |
|  | 25.2 | 22.1 | "      "    WOL (XY-X) |
| Y | 28.5 | 20.4 | Average of SEN and CN (YZ-Y) |
|  | 23.2 | 16.4 | "      "    WOL (XY-Y) |

(2) Crack plane orientations of comparative data is different from WOL specimen results.  For identical crack propagation directions.

Figure 1. WOL Specimen

CN – CENTER NOTCH SPECIMEN
WOL – WEDGE OPENING LOADING SPECIMEN
SEN – SINGLE EDGE NOTCH SPECIMEN
SB – SLOW NOTCHED BEND SPECIMEN
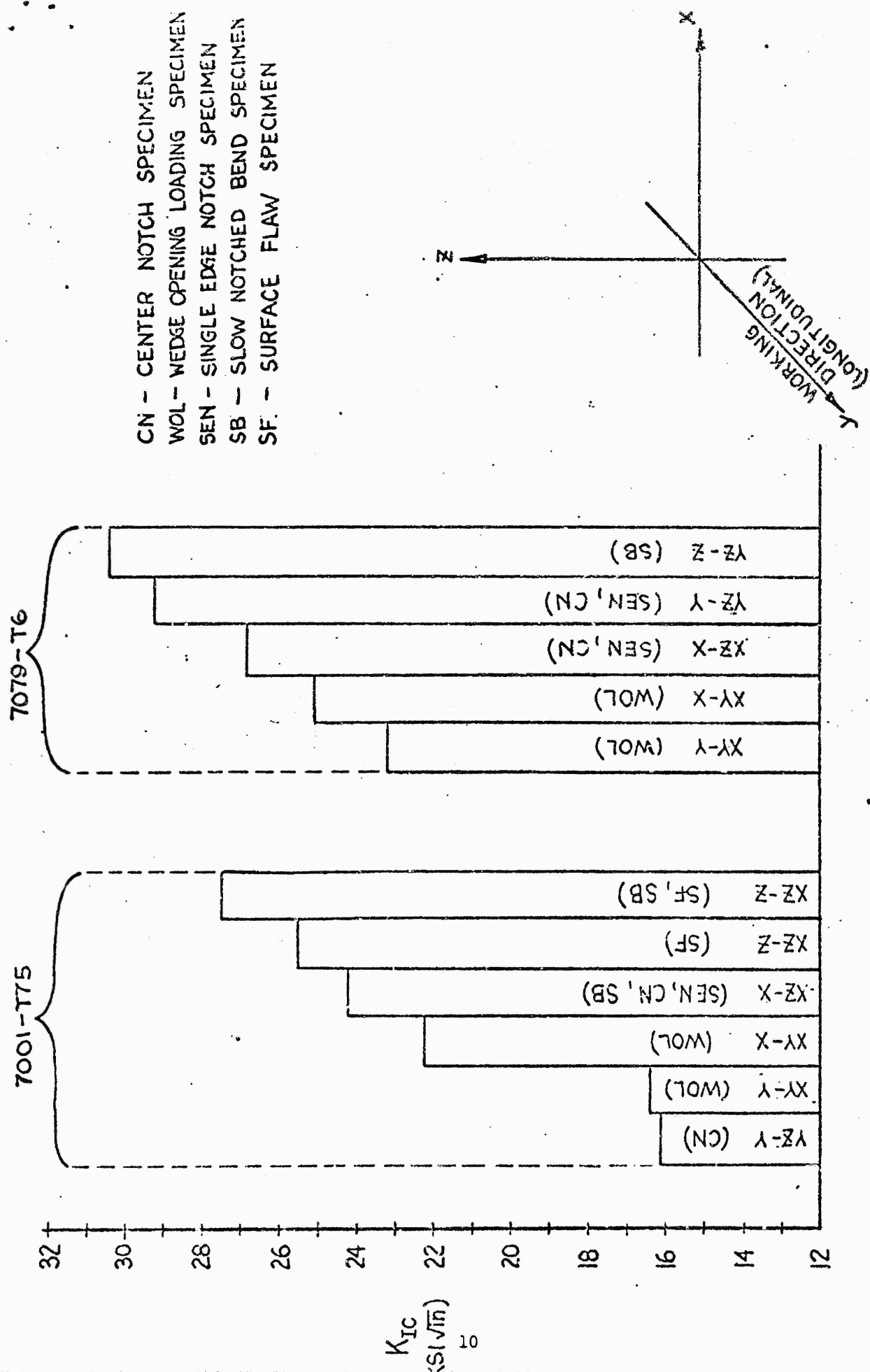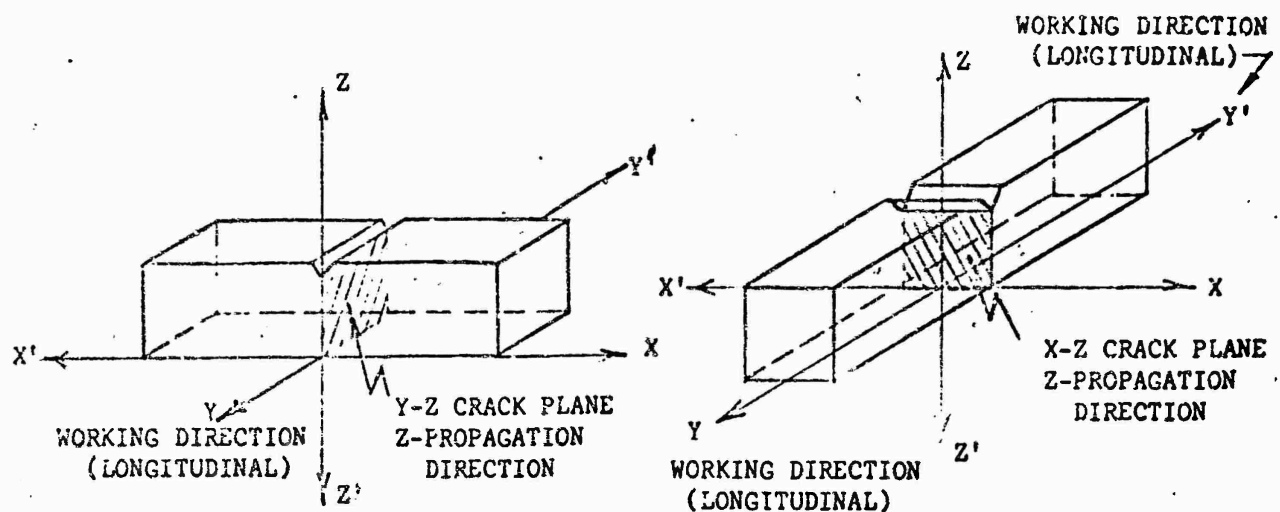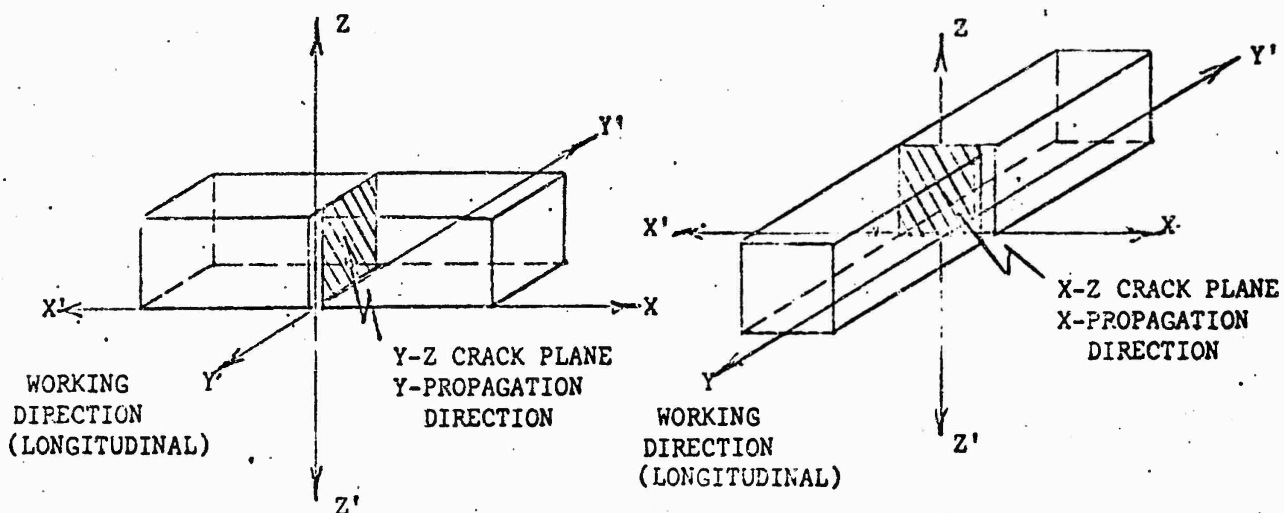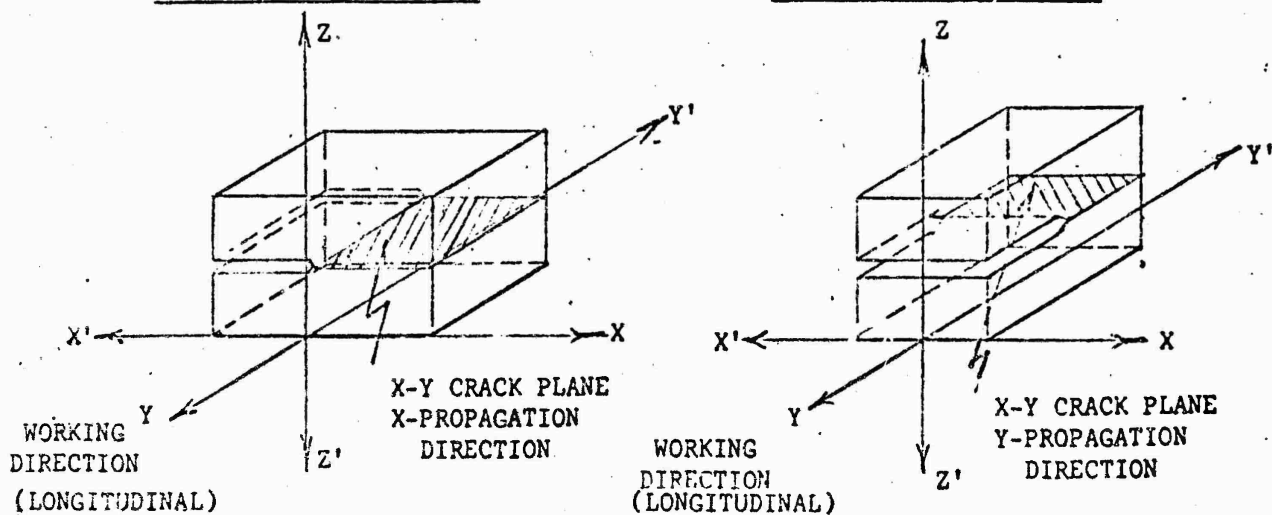SF – SURFACE FLAW SPECIMEN

AVERAGE $K_{IC}$ VALUES

Figure 2.

A) YZ-Z CRACK ORIENTATION

B) XZ-Z CRACK ORIENTATION

C) YZ-Y CRACK ORIENTATION

D) XZ-X CRACK ORIENTATION

E) XY-X CRACK ORIENTATION

F) XY-Y CRACK ORIENTATION

CRACK PLANE ORIENTATION AND CRACK PROPAGATION DIRECTION

Figure 6
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